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XIX.—*On the Organic Origin of the so-called 'Crystalloids' of the Chalk.* By H. C. Sorby, F.R.S. &c.

The appearance of Dr. Wallich's interesting paper, published in this Magazine (vol. viii. p. 52), in which he alludes to my having found in chalk objects similar to Coccoliths, induces me to give an account of my researches on the subject. I do not claim the discovery of such bodies in the Chalk, but to have been the first to point out that they are not the result of crystalline action, that they are identical with the objects described as Coccoliths by Prof. Huxley*, and that these are not single separate individuals, but portions of larger cells.

So far as I am aware, the illustrious Ehrenberg was the first who pointed out the ovoid bodies occurring in chalk, in a paper read at the Berlin Academy, Aug. 18, 1836, on "New Microscopic Characters of earthy and compact Minerals †." After alluding to the various minute bodies constituting some kinds of kaolin and agaric-mineral, he says that the most remarkable of all are those found in chalk, which shows small, flat, elliptical disks, similar to each other, consisting of only a few concentric rings, usually only one, and an internal nucleus of irregular character, as shown in his figure, pl. i. 2 B, in Pogg. Ann. He again alludes to them in his Memoir on Chalk and Chalk-marl ‡, saying that in a former paper he had declared that the preponderating substance of chalk, which forms the cementing material, was minute, elliptical, flat, granular bodies and their fragments. He looked upon them then, as he still continued to do, as concretions of a crystalline character, whose

* Deep-Sea Soundings in the North Atlantic Ocean, made in H.M.S. Cyclops. London, 1858.

† Monatsberichte, 1836; Poggendorff's Annalen, 1836, xxxix. 101.

‡ Abhandlungen der k. Akad. der Wissen. zu Berlin, 1838, 67.

form is peculiar to the chalk. In a note at p. 68, he ascribes them to the same kind of action as gave rise to the larger concretions met with in limestone- and clay-deposits, and considered the force which produced them not simple crystallization, though in some respects analogous, and proposes for it the term 'Crystalloid-Bildung.' The same idea is followed out in his paper on Concretions, read at the Berlin Academy, June 29, 1840*, in which he says he had endeavoured to make bodies like those in chalk by artificial chemical means, but had not succeeded, though he had made some to a certain extent similar. It must, however, be borne in mind that he looked upon them as *flat disks*, and not as *curved* in the manner shortly to be described. In his magnificent work, 'Microgeologie' (Leipzig, 1854), he also figures these ovoid bodies at pl. xxv. fig. B. 16, under the term 'Kreide-Morpholithe,' along with various minute radiating groups of crystals, evidently ascribing the whole to an inorganic action more or less closely connected with crystallization. In order to show to what extent such ovoid disks serve to make up some varieties of chalk, he gives (at pl. xxx. B) a highly magnified representation of the chalk of Rugen, and in various other plates shows that they constitute a very large proportion of the whole. It appears to me, however, a great exaggeration to affirm that chalk is *composed* of them, since a still larger part is made up of particles which we may attribute with confidence to the decomposed tissue of Foraminifera and other shells.

The inorganic nature of the ovoid bodies of the chalk has hitherto been almost universally adopted; for the only exception I am acquainted with is the supposition of the Rev. J. B. Reade†, who appears to have ascribed them to Infusoria. But when, about ten years since, I commenced studying the microscopical structure of chalk, I soon became convinced that both these explanations were unsatisfactory. By examining the fine granular matter of loose, unconsolidated chalk in water, and causing the ovoid bodies to turn round, I found that they are not *flat disks*, as described and figured by Ehrenberg, but (as shown by the oblique side view, fig. 5, p. 197) *concave* on one side and *convex* on the other, and indeed of precisely such a form as would result from cutting out oval watch-glasses from a moderately thick hollow glass sphere whose diameter was a few times greater than their own. This is a shape so entirely unlike anything due to crystalline or any other force acting independently of organization—so different to that of such round bodies, formed of minute radiating crystals, as can be made artificially and do really occur

* Neues Jahrbuch für Mineralogie, &c. 1840, 680; Journal für prakt. Chemie, 1840, xxi. 95; Ed. New Phil. Journ. 1841, xxx. 353.

† Mantell's Wonders of Geology, 2nd ed. vol. ii. 953.

in some natural deposits—and pointed so clearly to their having been derived from small hollow spheres, that I felt persuaded that such was their origin. The small cells of Foraminifera occurring in the chalk being just the size and thickness that would agree with this supposition, I endeavoured for a long time to make out that the ovoid bodies were in some way or other derived from them. I thought that, when decomposition took place, perhaps the calcareous matter might have re-arranged itself into more or less circular concretions whilst still in the form of the cells of Foraminifera, and thus, on further decay, they might have broken up into ovoid bodies of the form described above. I sought diligently for proof of this, but in vain, though I convinced myself that a very considerable part of the minute particles of the chalk was certainly derived from the decomposed tissue of Foraminifera. Notwithstanding this, I still adhered to the supposition of their having originated from organic spheres, and endeavoured to clear up the difficulty by studying recent deposits. Some eight or nine years ago, when examining mud from our own shores, I found one single body which was obviously similar to those in the chalk, both in form and optical characters, but was unable to make out its true nature.

In 1858 appeared Prof. Huxley's Report on the Deep-Sea Soundings in the Atlantic, in which, at p. 64, he says that in all the specimens, from depths varying between 1700 and 2400 fathoms, he had found "a multitude of very curious rounded bodies, to all appearance consisting of several concentric layers surrounding a minute clear centre, and looking at first sight somewhat like single cells of the plant *Protococcus*; as these bodies, however, are rapidly and completely dissolved by dilute acids, they cannot be organic, and I will for convenience' sake simply call them *Coccoliths*."

Still nourishing the conviction that ovoid bodies like those in chalk would be found in deep-sea deposits, at my request I was kindly furnished by Prof. Huxley with some of the Atlantic mud from a depth of 2230 fathoms. I was at that time as ignorant of what he had written on the subject as he was of my object, and of the connexion between the bodies he had described and the chalk. Directly I examined it with the microscope, I perceived that my long-cherished belief was true, and that this deep-ocean mud would completely explain the peculiar characters of our Chalk formations. Nor was this all; for on the 27th of August of last year (1860) I found that, as I had predicted several years before, the ovoid bodies were really derived from small hollow spheres, on which they occur, separated from each other, at definite intervals. I therefore read a short paper on the subject at the meeting of the Sheffield Literary and Philosophical Society, on the 2nd of October, in which I showed that the so-called crystalloids of the chalk are not of crystalline or concretionary origin, but are similar to ovoid bodies forming part of spherical cells in some respects analogous to the cells of Foraminifera.

Nearly two months after this, I had the pleasure of making the acquaintance of Dr. Wallich, who had just returned from his voyage in H.M.S. 'Bull-dog,' and found that he also had discovered the true origin of the Coccoliths, as described at p. 13 of his "Notes on the presence of Animal Life at vast Depths in the Sea, &c.," published for private circulation in November 1860, without having been aware of their important relation to chalk. Mr. Roberts, however, in his paper on "High and Low Life*," when alluding to Dr. Wallich's interesting discoveries, says, "Their discovery in a living state in this ooze is of high geological importance; for microscopical investigation, undertaken by Mr. Sorby, proves their existence in chalk-rocks, associated there, as they are in this North Atlantic Ocean, with Globigerinæ. Indeed, chalk itself is seen to be little else than a compacted mass of Foraminifera-shells, whole and fragmentary, and may be best described by using the very words by which Dr. Wallich introduces to science this recent deposit."

Having thus given a history of the subject, I will proceed to describe some of the facts I have observed, but at the same time shall not attempt to give anything like a complete account of the microscopical structure of chalk, which could not be done without a number of illustrations. Moreover, there are some interesting questions requiring further investigation, which I hope to describe in detail when treating on the microscopical structure of rocks in general. The drawings of Coccospheres and Coccoliths which I made nearly a year ago agree very closely with the figures accompanying Dr. Wallich's paper (pp. 53 & 54). I must confess that, as he justly observes, one is tempted to conclude that there is some connexion between Coccospheres and Globigerinæ; but, at the same time, I feel inclined to think that they may be an independent kind of organism, related to, but not the mere rudimentary form of, Foraminifera. Their optical properties are entirely different. Each cell of Globigerinæ, when alone or attached, gives a splendid well-defined black cross and coloured rings when examined with polarized light, which is readily explained by the fact of the shell being made up of minute crystals of calcite, arranged with their principal axis perpendicular to the surface of the shell. No such cross is, however, seen in the case of Coccospheres; and the cell-wall between the Coccoliths has such a very weak depolar-

* 'Geologist,' 1861, iv. 1.

izing action, that I very much doubt its calcareous nature. The individual Coccoliths, when on the spheres, or, still better by far, when detached, each give an extremely well-defined black cross; and their depolarizing action is much too powerful to allow us to suppose that this is due to the same arrangement of the carbonate of lime as in the shell of Globigerinæ, and that the Coccoliths are the commencement of calcification. At the same time it is not impossible that they might come off from the cells before general calcification took place; and I have found some shells of Foraminifera which showed imperfectly-defined oval bodies, giving black crosses with polarized light, thus proving that such a radiate arrangement of the carbonate of lime as that in Coccoliths does occasionally, though rarely, occur in the shell of Foraminifera. With respect to the individual Coccoliths, their optical characters prove that they have an extremely fine radiating crystalline structure, as if they had grown by the deposition of carbonate of lime on an elongated central nucleus, in accordance with the oval ringed structure shown in fig. 1 (magnified 800 linear).

In order to obtain a satisfactory knowledge of chalk, we should commence with the study of thin sections of the harder varieties. I am not aware that any one but myself has employed this method of research, but I have by this means succeeded in proving most completely that entire Foraminifera are comparatively rare, and make up only quite a small proportion of the whole. More or less detached and broken cells are, however, very numerous, so much so that in some cases they are almost in contact throughout the whole mass, and it is only the spaces between them that are filled with fine granular matter, which in some other specimens constitutes nearly the whole rock. In general, however, the constitution of chalk is intermediate between these two extremes. The nature of the granular matter is best learned by an examination of those very soft specimens which have not been much altered since deposition. When seen in water, under a bit of thin glass, with a power of from 400 to 800 linear, it is easy to perceive that a considerable part is made up of the decomposed tissue of Foraminifera. There are often also small well-defined groups of radiating crystals, similar to those named by Ehrenberg 'Krystaldrusen,' and figured on pl. xxv. B. 12–15 of his 'Microgeologie;' the nucleus is sometimes a minute fragment of the decomposed tissue of Foraminifera; and there can be no doubt respecting their crystalline and inorganic origin. They, however, differ entirely from the well-defined oval bodies hitherto described as chalk-crystalloids. These, in form and optical properties, are exactly similar to the Coccoliths of the Atlantic mud. When made to turn round, they both are seen to be concave on one side and convex on the other, as shown by the oblique side view of an unusually large one from the chalk, fig. 5 (magnified 800 linear); and they give the same kind of well-defined black cross with polarized light. Hence we must abandon the idea of their being "peculiar to the chalk," and may possibly be rather led to conclude that they are *characteristic of deep-ocean deposits*. Many of those in the chalk have a decided granular character, as shown in fig. 2 (magnified 800 linear). The rings, instead of being simple, are, as it were, made up of separate beads; and the centre is also of a compound granular character, with various modifications. Judging from Ehrenberg's drawings, and from what he says at p. 136 of his paper on Chalk and Chalk-marl, he appears to look upon this granular structure as their universal character, and concludes that their minute constituent granules were derived from decomposed Foraminifera, and were afterwards arranged into crystalloids by means of some unknown crystalloidal force. However, as already stated, some show no such granular structure, but are precisely similar to those in the Atlantic mud; and the granular constitution of the others admits of a very simple explanation. As is well known, when shells become fossil, they often acquire a crystalline texture; and, in fact, this occurs in the recent dead shells found in the mud of the Mediterranean, described by Marcel de Serres and Figuier *. I have also succeeded, beyond all expectation, in producing artificially the same change in recent shells by keeping them for a month or two in a dilute solution of caustic potash, at a temperature of about 145° C. (293° F.), which, by dissolving the organic matter, permits the carbonate of lime to crystallize according to a new arrangement; and not only do shells consisting of aragonite undergo this change, but also sometimes those made of calcite†, though, in the case of fossils, it has often only occurred in those composed of aragonite. If such a molecular re-arrangement were to take place in the Coccoliths of the Atlantic mud, they would become almost exactly like the granular specimens found in the chalk; and I shall be much surprised if I do not succeed in imitating them by such artificial means as I have just described.

* Annales des Sciences Nat. 3 sér. 1847, vii. 21; Comptes Rendus, 1846, xxii. 1050; Neues Jahrbuch für Mineralogie, 1848, 873; Edinburgh New Phil. Journ. 1847, xlii. 381.

† See Rose's second treatise on Carbonate of Lime, Abhandlungen d. k. Ak. d. Wiss. zu Berlin, 1858, 63, since confirmed and extended by my own experiments.

Though the facts I have already stated appear to me conclusive, yet it is of course satisfactory to find that, though rarely seen to advantage, compound Coccospheres do really occur in the chalk; and, indeed, I had seen and made a drawing of one nearly ten years ago, without having properly understood its nature. They, however, like the Foraminifera, appear to have undergone much more decomposition in the chalk than in the fresh mud of the Atlantic, which is only what might have been expected.

But, besides simple ovoid Coccoliths, and others modified by various marks and apertures, there occur in chalk minute bodies which are apparently somewhat related to them, but differ from anything hitherto found in the Atlantic mud. As an illustration of these, I refer to figs. 3 and 4 (magnified 800 linear). Those like fig. 4 are similar to Coccoliths in being oval and spoon-shaped, but show four marks, arranged in a cross, instead of two, or a single elongated nucleus. When bodies like fig. 3 are made to turn about, the under side of the broad end is seen to be like fig. 4, which is, in fact, so to speak, the ground-plan of fig. 3. There are various forms of these curious objects, which are obviously of organic origin, and may be described as Coccoliths with a sort of spine growing outwards from the centre. These spines are four-sided, are sometimes pointed, sometimes end in a small cross, and sometimes extend into four well-developed wings. When the ovoid base occurs alone, either owing to the spine having been broken off or never developed, it is difficult to distinguish them from some varieties of Coccoliths, or at all events to point out any essential and widely remote difference; and therefore, though I have not yet met with sufficient evidence to prove it, I cannot help thinking that at the Chalk period there was a form of Coccosphere in which the Coccoliths were to a greater or less extent developed into small spines.

It is not easy to determine the extent to which these various ovoid organic fragments serve to make up chalk; but, like the Coccoliths of the Atlantic mud, and to a very similar extent, they and their fragments do certainly constitute a very material proportion of the whole. If to them we add the more or less entire and broken Foraminifera, and such particles as can be shown to result from their decay and from the decomposition of the shells of *Inoceramus*, it appears to me that we are in a position to completely account for the origin of the deposit. The importance of the fact of thus being able to make out the true nature of the so-called 'crystalloids' is, that we can no longer doubt the almost entirely organic origin of chalk. Had they been due to a kind of crystalline action, we might indeed have had good reason for supposing, with Ehrenberg, that the carbonate of lime of which they are composed was derived from decayed Foraminifera; but at the same time a strict proof would have been wanting, and we might have adopted the opinion expressed by Haidinger in his paper on the Metamorphism of Rocks *, and concluded that, though, according to Ehrenberg, chalk does contain very many organic bodies, it does itself consist of rounded forms, which are a chemical deposit from water containing soluble salts of lime. Now, however, that their real origin appears to be established, it is no longer requisite to assume the existence of any unknown crystalloidal force differing from simple crystallization; and we can clearly perceive that, though presenting characteristic differences, chalk is in every respect analogous to what we should have, if the mud now being formed at great depths in the Atlantic, by the accumulation of various minute organic bodies, were to be subsequently more or less altered by molecular changes or chemical actions of a well-known character. There is, however, one striking difference; for the Atlantic mud contains many Diatomaceæ, spicula of Sponges, and other silicious organic bodies, which are very rare in, or absent from, the chalk: it contains, however, silicious concretions; and this contrast in the state and aggregation of the silicious matter in the two otherwise analogous deposits makes me very much inclined to conclude, with Ehrenberg †, that the silex of the flints was derived from disseminated silicious organic bodies, which has collected round various centres of segregational attraction,—though there are some difficulties to remove before that opinion can be finally adopted.

XX.—*On the Sexual Life of Plants, and Parthenogenesis.* By Dr. H. Karsten, Lecturer on Botany at the University of Berlin.

[Concluded from page 99.]

Embryogeny.

The elongated pollen-cells on the stigma of *Cœlebogyne ilicifolia* exhibit no peculiarity in the onward course they pursue to the nucleus of the ovule. The amylum and the vesicles with nitrogenous contents (mucus-vesicles) become dissolved as the pollen grows; and when the pollen-tube has reached the large embryo-sac, it is seen to be filled with fluid, which also in all probability contains a number of vesicles, freely swimming about in it, some with and others without nuclei.

* Haidinger's Wiener Mittheilungen, 1848, iv. 103; Neues Jahrbuch für Mineralogie, 1849, 213.

† Abhandlungen d. k. Ak. d. Wiss. zu Berlin, 1838, 82.